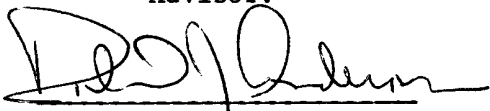


HISTORY AND DEVELOPMENT
OF THE ROCKY MOUNTAIN OVERTHRUST
AS A HYDROCARBON POTENTIAL

For Senior Thesis
Presented in Partial Fulfillment for the Degree of
Bachelor of Science

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Abstract

In recent years the worlds petroleum resources have dwindled drastically, this combined with exorbitant prices for foreign oil the United States has a great need for new oil exploration. Much of this new exploration has occurred in the western United States, aligned along the overthrusts and disturbed belts that extend from Canada to Mexico. This paper reviews the history of the Rocky Mountain Overthrust and the developments in petroleum exploration along it. Finally, the author attempts to draw some conclusions as to locations of other possible fields along the thrust zone and their possible importance to the petroleum supply.

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Definition and Mechanics of Movement

To begin a thesis of this nature one must have at least a working knowledge of the actions involved in overthrust faulting. At present the most satisfactory genetic classification is based on the nature of the relative movement along this fault. The term overthrust deals with a fault in which the hanging wall moves up relative to the foot wall, has a dip of less than 10° and where there has been great horizontal displacement, essentially at right angles to the regional trend of the fault (Billings 1972)

Although this definition is easily understood the actual mechanics of movement are quite detailed and at best are general mathematical analyses of possible cases. As elementary mechanics would suggest the forces necessary to move large masses of rock would surely rupture it before movement took place. An analysis of a simple situation will illustrate the complexity of the overthrust model. As may be expected the coefficient of friction between the over and under lying blocks is a major parameter and will be considered first. If the fracture is horizontal (Fig 1):

$$\mu = \frac{F}{W} \quad (1)$$

where μ is coefficient of friction, W is the weight of the upper block, and F is force necessary to push it.

$$W = bcd \rho g \quad (2)$$

where b , c , and d are dimensions of the block, ρ is specific gravity of the rock, and g is acceleration of gravity.

$$F = \mu cd \quad (3)$$

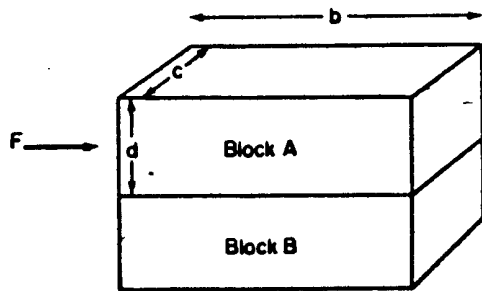


Fig. 1. Horizontal fault. Block A pushed over block B when subjected to compressive force F .

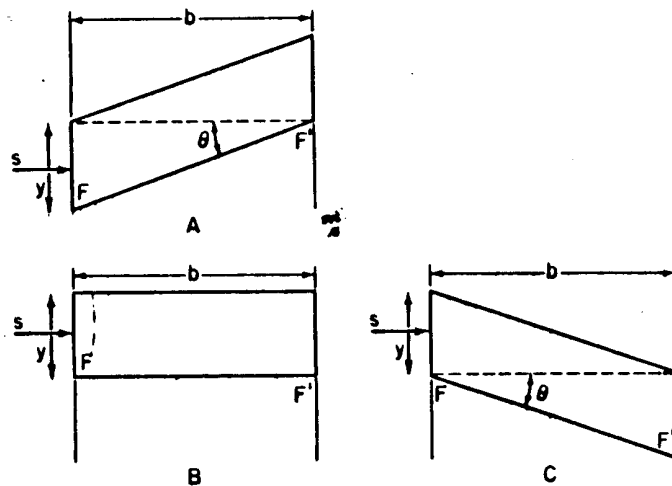


Fig. 2. Fault block being pushed along a fault plane. (B) Horizontal fault plane. (C) Fault block pushed downslope. (A) Fault block pushed upslope.

(HAYES 1976)

where s is force per unit area, and c , and d are dimensions of face on which compression is being exerted.

Substituting equations (2) and (3) in equation (1),

$$\mu = \frac{scd}{bcd\rho g} \quad (4)$$

$$s = \mu b\rho g \quad (5)$$

For example, if b is 20 km ($= 2 \times 10^6$ cm), if μ is 0.5, and ρ is 2.3 g/cm³,

$$s = 2.25 \times 10^9 \text{ dynes} \quad (6)$$

But since S exceeds the crushing strength of the average rock (7×10^8 dynes/cm²), the block would break up before it could move.

Equation (5) can be recast to the form

$$B = s/\mu\rho g \quad (7)$$

where B is maximum possible size of the thrust sheet, S is crushing strength of a rock (7×10^8 dynes/cm²), and other parameters are as before. Substituting in equation(7)

$$B = 6.2 \times 10^5 \text{ cm} = 6.2 \text{ km} \quad (8)$$

But most fault planes are inclined. If the fault plane dips toward the source of the active pressure the thrust block is pushed uphill. The compressive force must be great enough not only to overcome the friction, but also to lift the block.

If the thrust block is shaped as in Fig 2, the horizontally directed stress to move it is,

$$s = \frac{b\rho g (\mu + \tan \theta)}{(1 - \mu \tan \theta)} \quad (9)$$

where Θ is the dip of the fault plane, and the other parameters are as indicated above.

The maximum possible size of the thrust block is,

$$B = \frac{s (1 - \mu \tan \Theta)}{\rho g (\mu + \tan \Theta)} \quad (10)$$

If $\mu \tan \Theta > 1$, $s = \infty$, and $B = 0$.

For example, $\mu = 0.5$, $\mu \tan \Theta = 1$ when $\Theta = 63^\circ.5$. In other words, under postulated conditions, a block can not be thrust up along a fault dipping more than $63^\circ.5$. It should be emphasized that one assumption is that the compressive force is horizontal (Billings 1972). These equations demonstrate the complexity of the overthrust model. As is indicated in the equations along with related factors (pore pressure) which may in part balance the lithostatic pressure the overthrust is an element with many variables. In fact so many factors are involved precise mathematical analysis of a specific case is impossible and will give only the order of magnitude (Billings 1972).

Importance of Overthrusting

From the preceeding chapter evidence was cited for the mechanics of movement and folding of strata during overthrusting. The importance to the petroleum geologist is that the thrust faulting provides the mechanisms for simultaneous accomplishment of the following processes:

(1) burial of organic rich, thermally immature rocks to depths where temperatures are sufficient to cause generation and expulsion of liquid hydrocarbons; (2) emplacement of petroleum in reservoir beds of an uplifted section which already had attained its maximum depth of burial; and (3) creation of structures suitable for trapping of the emplaced petroleum (Swetland, Patterson, Claypool 1978).

Although each of these processes may in fact occur alone, or in conjunction with each other, each process has its own limiting factors, which will control the final production of hydrocarbons. The organic source rock is limited by quantity, quality degree of maturation and possiblity of subsequent migration. The reservoir rocks are controlled by their thickness, porosity, and their degree of permeability. The trap structures and their relevance are controlled by the type of trap, the trap capacity, the seal and timing of development of the trap in conjunction with hydrocarbon generation. The last and probably the most important limiting factor is the preservation of accumulated hydrocarbons in traps until suitable exploration techniques allow for discovery then extraction of them (Parker 1979).

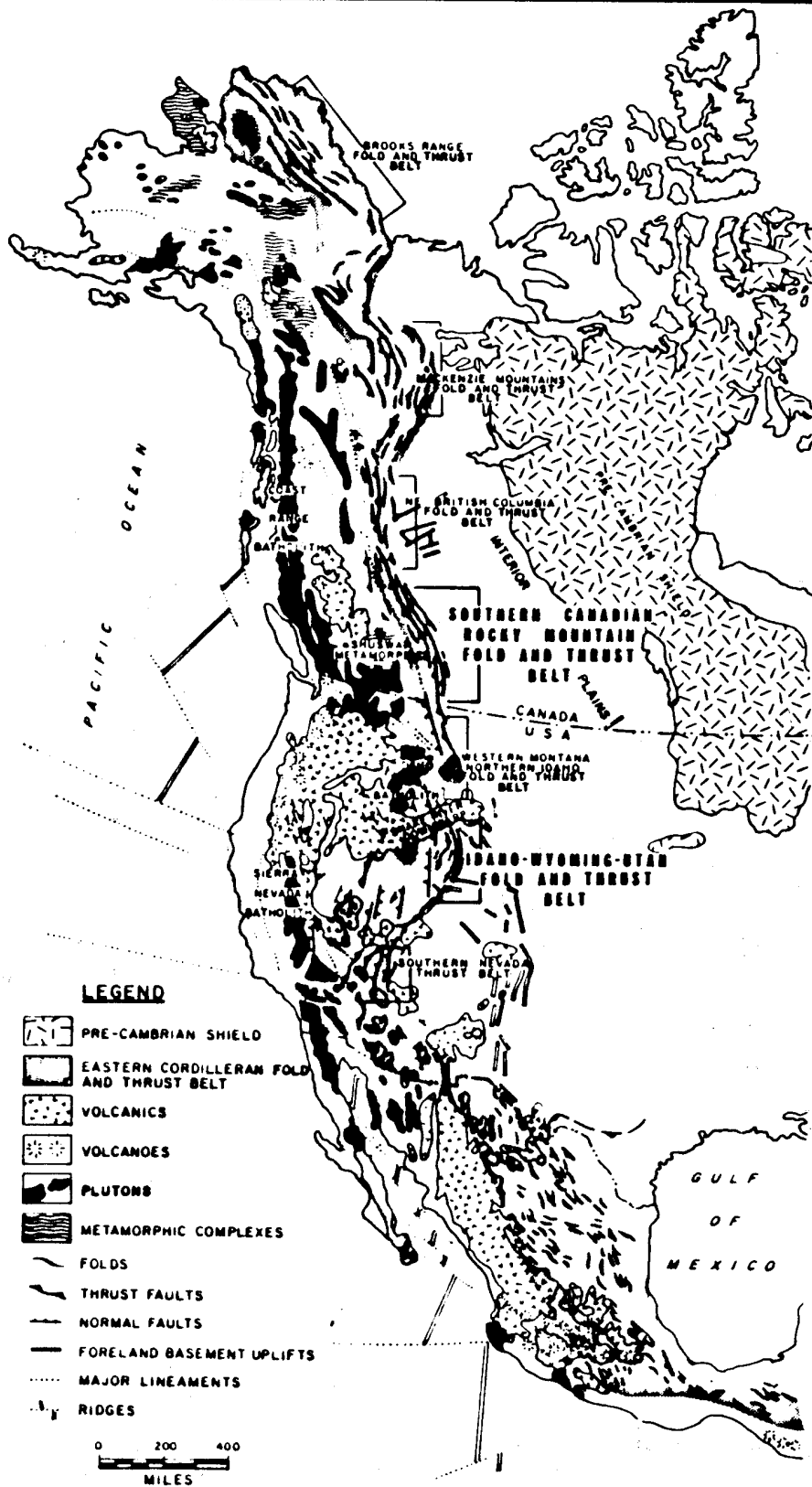
If generation and expulsion of hydrocarbons occurs most petroleum is trapped in asymetric hanging wall folds at the leading edges of the thrust

sheet. Effective closures are commonly located at a relatively external part of a thrust belt and at shallow to moderate structural levels (10,000 ft). At this depth and position strata has been only slightly to moderately disrupted by faulting allowing reservoir continuity and migration pathways to remain essentially intact (Harding & Lowell 1979).

Another factor of overthrust faulting that is of major importance, although not directly involved in hydrocarbon accumulation, is the actual horizontal shortening of the geologic sequence. The supra-crustal rocks of southern Canada have been estimated to be horizontally shortened by 200 km (Price 1979) and those rocks in the thrust belt of Wyoming, Idaho, and Utah have been shortened 65 miles (104.5 km) of an original 130 miles (209 km) or about 50% (Royse, Warner, Reese 1977).

Location of Overthrust

The greater Cordillera hinge line and overthrust belt of the western United States is one of the few remaining onshore exploration frontiers on the North American continent (Powers 1977). The Cordilleran orogenic belt is considered to be a single tectonic element extending from Alaska to Central America (Powers 1980) (Fig. 3). It is a complex zone consisting of extremely thick sedimentary wedges which have been extensively deformed, batholithic intrusions with associated regional metamorphism, volcanic eruptions, and regional uplift. The eastern most sectors of the Cordillera are the fold and overthrust belts (Hayes 1976).



GENERALIZED TECTONIC MAP OF WESTERN NORTH AMERICA

FIG. 3 (HAYES 1976)

Simplified After P. B. King, (1969)

Canada

The Canadian Disturbed belt is perhaps the best geologic analog to the United States Overthrust belt. The Canadian Cordillera as well as the Idaho-Wyoming-Utah thrust belt hinge line stratigraphy are composed of an older miogeocline platform assemblage, and a younger syntectonic clastic wedge sequence. These clastic wedge sequences have subsequently been deformed by overthrusting and folding (Hayes 1976). These similarities are based upon a number of characteristics common to both areas such as general structural configuration, trap types, reservoirs, stratigraphy, timing of migration of hydrocarbons, depth of burial, and age of tectonic movement. There are, however, significant differences such as the age of major source rocks and the paleothermal histories (Powers 1980). Further details of the tectonic history as it relates to the Idaho-Wyoming-Utah thrust belt will be included in the next chapter dealing with Idaho, Wyoming and Utah.

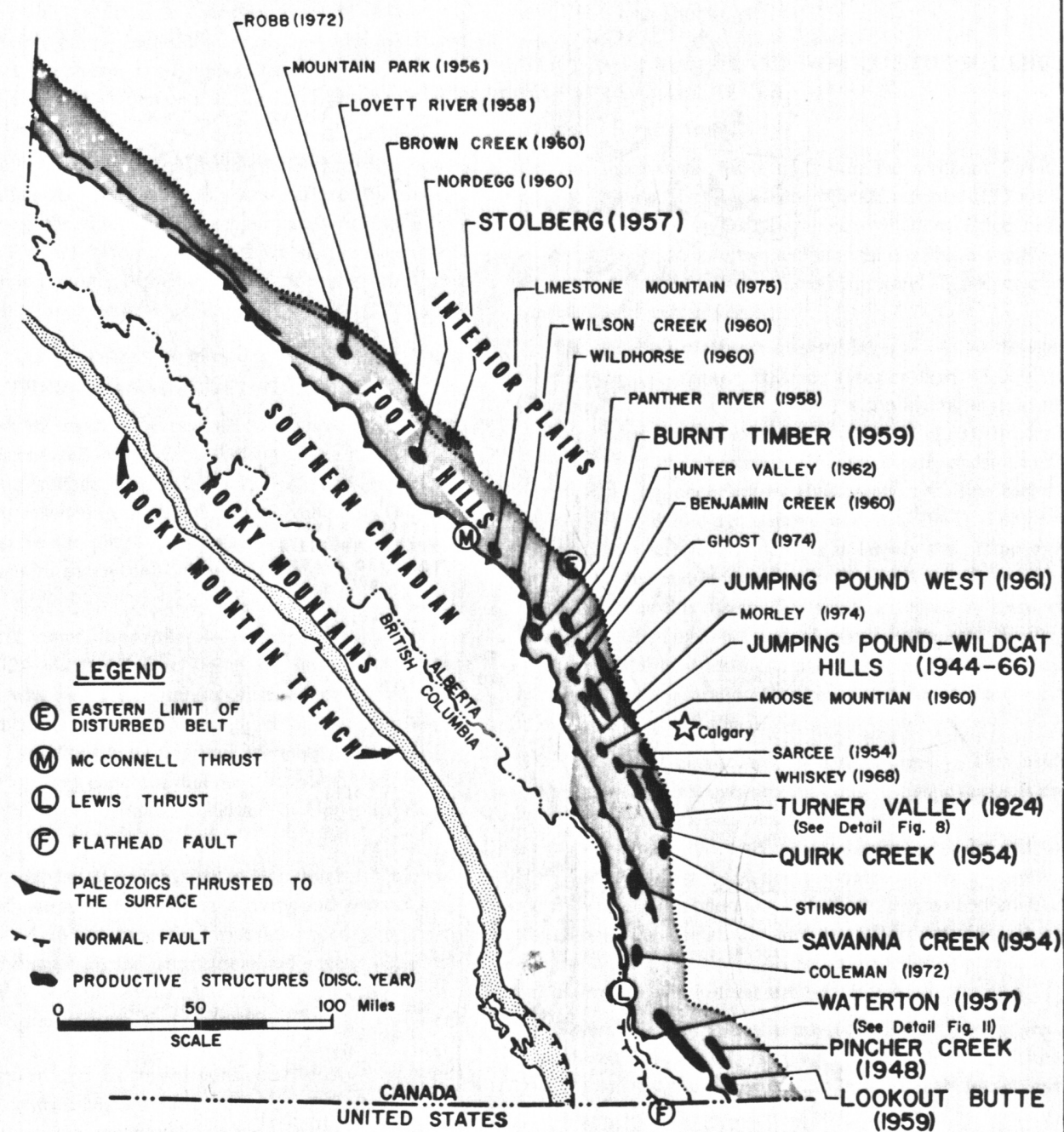
The eastern sector of the Canadian Cordillera has been extensively explored, resulting in the discovery of natural gas, natural gas liquids, sulfur, and over one billion barrels of oil. These discoveries were due to structural interpretations that evolved from geological, geophysical, and geochemical exploration. These interpretations were then compared to a less geologically explored region, the Idaho-Wyoming-Utah thrust region, as an analogy for geologic explorations and hydrocarbon potential.

The earliest commercial efforts for development of hydrocarbon resources in the Southern Canadian Rocky Mountain thrust belt concentrated on utilizing surface structures in close proximity to known surface

manifestations of oil and gas. Although the economic gain from these ventures was modest. They did, however, provide proof of hydrocarbon existence in the subsurface and its definite relation to surface geology (Hayes 1976).

The first major oil field discovery which generated the oil boom was the Turner Valley oil field in 1936. The complex nature of the subsurface of the thrust zone caused many geologists of the time to declare the total basement sequence of the thrust belt to consist of Upper Cretaceous shale. Needless to say, few new major oil fields were to be found using the earlier mapped surface structures. Modern techniques in geophysical exploration and structural interpretation, combined with the economic feasibility of recent years, has made possible the discovery of many new fields in the fold and thrust belt. The locations of producing structures, are shown in Figure 4. The actual complexity of the subsurface is shown in Figure 5.

The most prolific reservoirs in all of the southern Canadian thrust belt, are porous Mississippian carbonates of the Rundle Group, which lie below the pre-Jurassic unconformity (Hayes 1976), accounting for 87% of the inplace reservoirs (Gordy 1980) (Fig 6). Source rocks are probably Middle and Upper Devonian organic rich carbonates and shales, Mississippian Exshaw, Jurassic Fernie, and the Cretaceous Blackstone and Wapiabi shales. As all source rocks they contain varying concentrations of plant and animal debris that have generally accumulated with fine grained inorganic matter. Production and preservation of the organic debris are controlled by the physico-chemical conditions of the depositional environment (Hayes 1976).



**LOCATIONS OF PRODUCTIVE STRUCTURES
OF THE
SOUTHERN CANADIAN ROCKY MOUNTAIN FOOTHILLS**

(Refer to schematic cross section, figure 5)

FIG. 4 (HAYES 1976)



TABLE OF FORMATIONS
FOOTHILLS & FRONT RANGE STRATIGRAPHY
WEST OF CALGARY

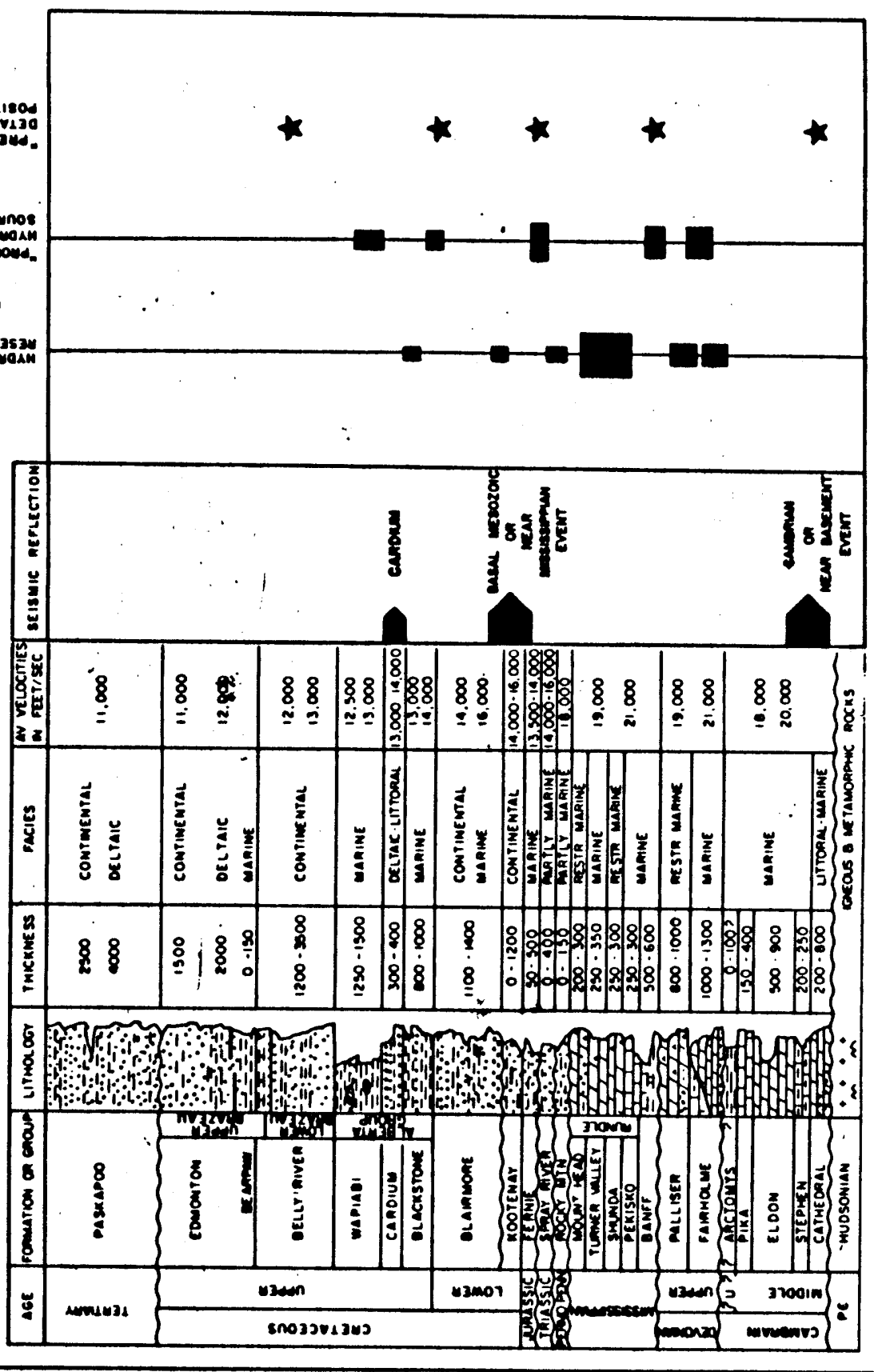


FIG. 6 (HAYES 1976)

In Part After Gordy et al. (1975)

Idaho-Wyoming-Utah

The Idaho-Wyoming-Utah (I-W-U) thrust belt contains many of the most widely described thrust faults in the western United States. The Bannock and Absaroka thrust faults are described in many textbooks on structural geology, and may be two of the earliest known thrust faults in North America (Armstrong, Oriel 1965). As was the case in the southern Canadian Rocky Mountains, initial exploration was done primarily in the vicinity of oil seeps and springs (Hodgden, McDonald 1977). The I-W-U area is rich in coal, oil, gas, and also encompasses one of the larger mineable phosphate fields in the world (Armstrong, Oriel 1965). As the scope of this paper is focused on the petroleum resources of the Rocky Mountain Overthrust belt, the rich coal and phosphate deposits are mentioned in passing for those who wish to research further the developments of these valuable resources.

The following section will use the Idaho and Wyoming thrust belt as an example for the general paleoenvironment of the Rocky Mountain thrust belt. This section can then be related to other sequences because similar events occurred along the cratonic margin with only minor variation.

During Paleozoic and Mesozoic times about 100,000 aggregate feet of sedimentary rocks were deposited in the miogeosyncline of Western Wyoming and neighboring south eastern Idaho. This sequence is directly analagous to the depositional environment of the Southern Canadian Cordillera (Hayes 76). This deposition was not entirely constant in thickness with time nor lateral extent. Maximum depostion occurred in south eastern Idaho and thinned eastward on to the shelf margin in western

Wyoming. All Paleozoic rocks deposited in the miogeosyncline of south eastern Idaho were marine. They all exhibited the same east to west thickening off the shelf from midstate Wyoming. Early in the late Triassic, a northeast trending ridge arose through mid state Idaho, shedding detritus eastward. Nonmarine conditions existed due to this topographic high during late Triassic through early Jurassic. The shelf that had persisted through the Paleozoic, was not as evident in the Jurassic, and thick Jurassic sediments are found in western Wyoming. The detritus supplied in early Jurassic is responsible for the formation of the Jurassic Nugget sandstone, which later will become a very significant formation to the petroleum geologist. Subsequently, by late Jurassic, the topographic high moved eastward, destroying the miogeosyncline permitting the sea to return. Under marine conditions the Twin Creek limestone, also important to the petroleum geologist, as well as the Preuss and Stump sandstones were deposited.

It is appropriate at this time to summarize the major purpose of exploring this tectonic history. As the miogeosyncline shifted east the deposition of eastward thinning detritus produced conditions favorable for the development of hydrocarbons and stratigraphic traps.

With the destruction of the miogeosyncline in late Mesozoic, a period of folding of large north trending folds began. This folding was accompanied by eastward movement along the overthrust zone on the eastern flank of the miogeosyncline.

The 200 mile long by 60 mile wide thrust belt forms an eastwardly convex arcuate zone from the Snake River Plain south into Utah. The four major thrusts of the belt are, from west to east, the Bannock, which includes the Paris and the Willard thrusts, the Meade-Crawford thrust, the Absaroka, and the Darby which includes the Prospect, and Darby-Hogsback thrusts (Royse, Warner, Reese 1977). Strata above and below each of the faults is folded. This folding was once thought to have occurred preceeding faulting, but it is now considered to have developed simultaneous to faulting. Minimum horizontal displacement along the fault is ten to fifteen miles with a stratigraphic displacement of approximately 20,000 feet. Age of thrusting for the Prospect has been determined to be early Eocene, the Absaroka has been dated as latest Cretaceous. The first movement of the Paris occurred during latest Jurassic and earliest Cretaceous. As these thrusts developed they formed traps and reservoirs into which hydrocarbons migrated.

There is yet another episode in the tectonic history of the thrust belt which is significant in the control of migration of hydrocarbons. This is the period of block faulting which began in the Eocene and continues up to the present. This block faulting, which was very intense in the western portion of the thrust zone, may so have disrupted hydrocarbon concentrations that accumulated prior to block faulting, that the hydrocarbons have hence escaped late in the tectonic history (Armstrong, Oriel 1965). These same block faults could however also have provided channels and migratory pathways that hydrocarbons moved along to new resevoir rocks higher in the strata.

Other than the block faulting and general folded nature of the strata as structural constraints for hydrocarbon migration, there are a few other possibilities to consider. Localized as well as regional basins and arches play an important role in the migration of hydrocarbons. In the area of the Idaho-Wyoming-Utah Overthrust the Moxa Arch (Fig. 7), beneath the Absaroka thrust, acts as a control of potential oil reservoirs.

The most recent data continues to show considerable interest in exploratory drilling and wildcatting in the Overthrust. In Wyoming the overthrust belt was the area of the state that attracted the greatest attention during 1980 (TeSelle, Miller, Thames, Sonderby, Sheperd 1981). During this year 27 exploratory wells were drilled in the overthrust with a 37% success ratio. New wells include gas and oil production in the Jurassic Nugget Sandstone. Increased drilling at depths has also yielded production from deeper Triassic, Permian, Pennsylvanian, Mississippian, Devonian, and Ordovician horizons (TeSelle, Miller, Thames, Sonderby, Sheperd 1981). Production in the Wyoming thrust area should increase tremendously in the future with the completion of gas separation plants and pipelines by Amoco and Chevron.

Drilling in Idaho was up 300% in 1980 over 1979. These wells were confined to the Idaho portion of the Overthrust belt. Although no commercial production has been established to date, several of the unsuccessful new field wildcats did produce shows of oil or gas and completion of the wells had begun. Primary objectives of these wells range from the Cretaceous Bear River to the Ordovician Big Horn formations (TeSelle, Miller, Thames Sonderby, Sheperd 1981).

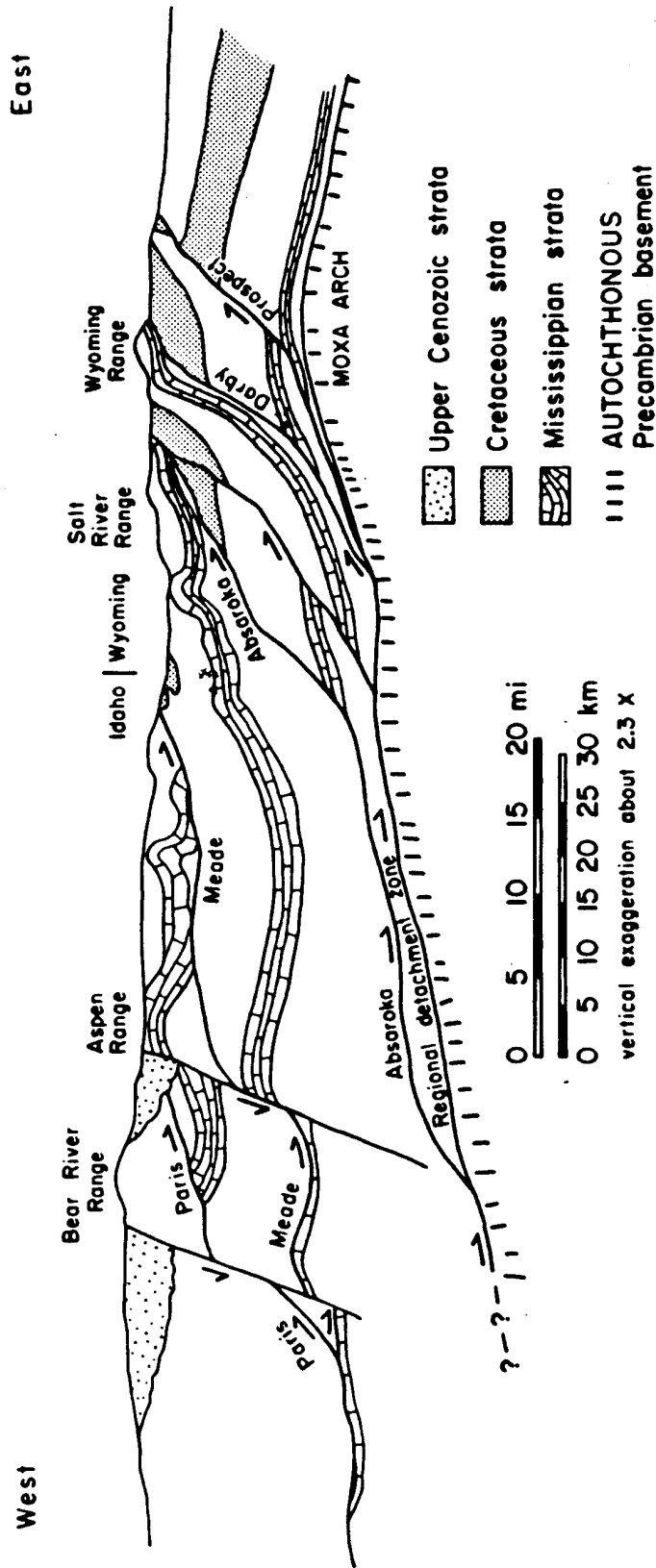


FIG. 7--Generalized schematic cross section across Idaho-Wyoming thrust belt along line AA' of Figure 1 (after cross section XX' of Royse et al, 1975), illustrating west-dipping sledrunner form of thrust faults and duplication of section.

(JORDAN 1981)

The main impetus for production along the Overthrust began with the discovery in January, 1975, of the Pineview Field in north eastern Utah. Production there is from the Jurassic Nugget and Jurassic Twin Creek formations. The best area source beds are Cretaceous shales (Rosenfeld, Ho, Dembicki 1980). The oil is found in traps near the leading edge of the west dipping thrust sheet. There are two migration paths possible: (1) Petroleum formed in deeper Jurassic and Triassic sediments in the west and migrated updip to the leading edge. (2) A vertical migration from Cretaceous marine shale which reached optimum thermal maturity for hydrocarbon generation below the overthrust sheet (Swetland, Patterson, Claypool 1978).

Montana

The disturbed belt of Montana lies on the hingeline between two regional structural features, the Rocky Mountain geosyncline on the west and the Central Stable Platform on the east. This encompasses parts of Glacier, Pondera, Teton, and Lewis and Clark counties in the northwestern part of the state. It lies west of the Sweetgrass Arch and includes the Rocky Mountain Front Ranges of Western Montana. The western limit is delineated by the outcrop of Precambrian Belt Rocks west of the Continental divide. The eastern limit is defined by a line, east of which rocks are relatively undisturbed on the west flank of the Sweetgrass Arch. The disturbed belt is characterized by a zone of overthrust faulting and folding extending from the Missouri River northward 125 miles to the International border (Hurley 1959). The Overthrust belt consists of a zone of Precambrian rock thrust over Paleozoic and Mesozoic rock during the Laramide orogeny of late Cretaceous and early Tertiary (McCaslin 1981). The zone is composed of convex eastward thrusts and folds that include the major Eldorado-Lombard overthrust. East of and structurally below the Eldorado-Lombard overthrust is the Disturbed belt, with deformed rocks ranging in age from Precambrian to early Tertiary.

The Disturbed belt here forms a salient extending eastward into the foreland. It is bounded in the north by thrusts having a left lateral component of movement, and bounded on the south by faults with right lateral shift. Deformation is most intense in the western sector of the Disturbed Belt and dies out eastward where the gentle folds merge with the

Rocky Mountain foreland. The salient is underlain by an eastern yielding decollement bounded by tear thrusts to the north and dies out south and eastward beneath the folds. Deformation resulted from piling up of imbricate thrusts and folds where the major Eldorado-Lombard Overthrust sheet, of the Cordilleran orogen, moved up and onto the foreland margin. The strata of the Disturbed Belt have been folded independently of the basement rock with crustal shortening above the decollement (Woodward, Lee 1981).

Montana's Disturbed Belt contains three distinctive trap types, one formed at the wedge edge of the thrust, a second formed by drag folding, and a third found in folded fault planes. The most common type of trap is the wedge edge trap, formed by the thrust fault having a steeper dip than the sediments it transacts (Fig. 8). The drag fold trap is more common in the less competent Mesozoic rocks. A product of the drag folding is that the formed anticlines have an axial plane that dips west (Fig. 9). That is, the crest of an anticlinal axis of a younger Mesozoic fold will be to the east of an older Paleozoic fold. The third type of trap (Fig. 10), formed in a folded fault plane, may have been formed from thrusting over deep seated structures, or by subsequent folding after thrusting. In any case, the structure on the upper plate will approximately reflect the structure of the lower plate. There are exceptions, when the upper plate is folded during thrusting and then may only reflect the structure of the lower plate by coincidence (Hurley 59).

TYPE I

WEDGE EDGE

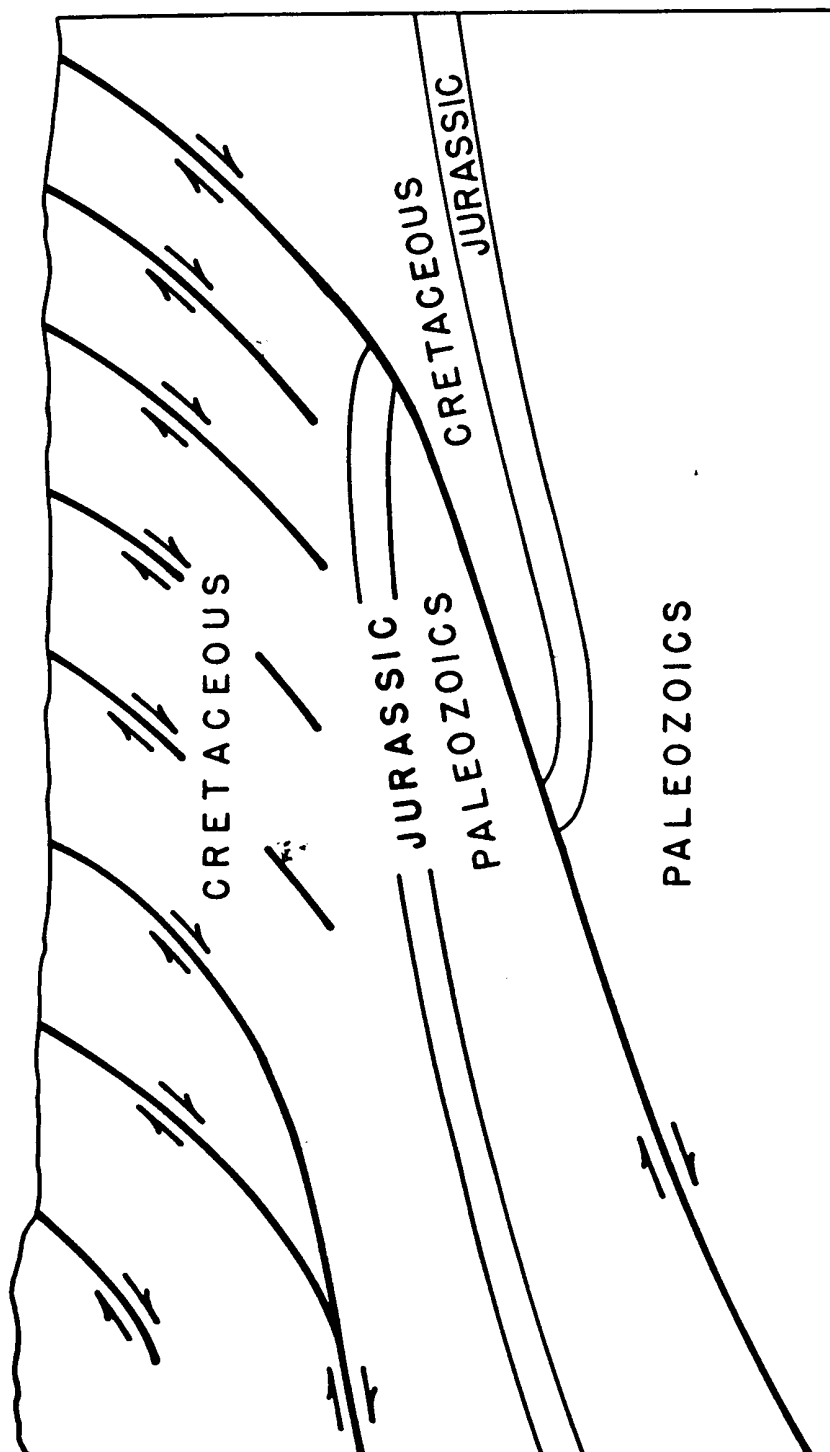


Figure 8. Diagrammatic Cross Section showing wedge edge traps of Montana's Disturbed Belt.
(HURLEY 1959)

TYPE II

DRAG FOLDS

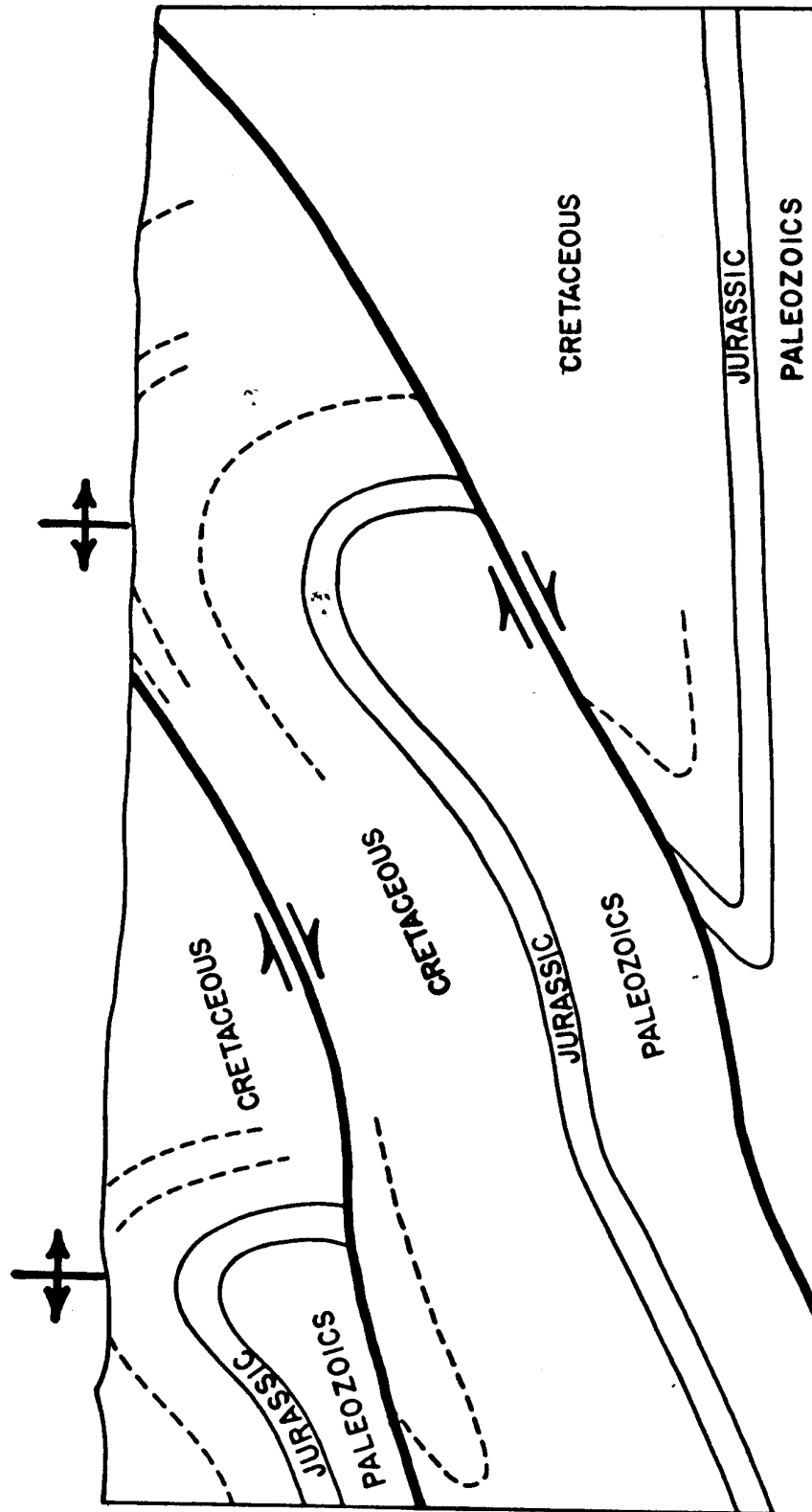


Figure 9. Diagrammatic Cross Section showing drag fold trap of Montana's Disturbed Belt.
(HURLEY 1959)

TYPE III FOLDED FAULT PLANES

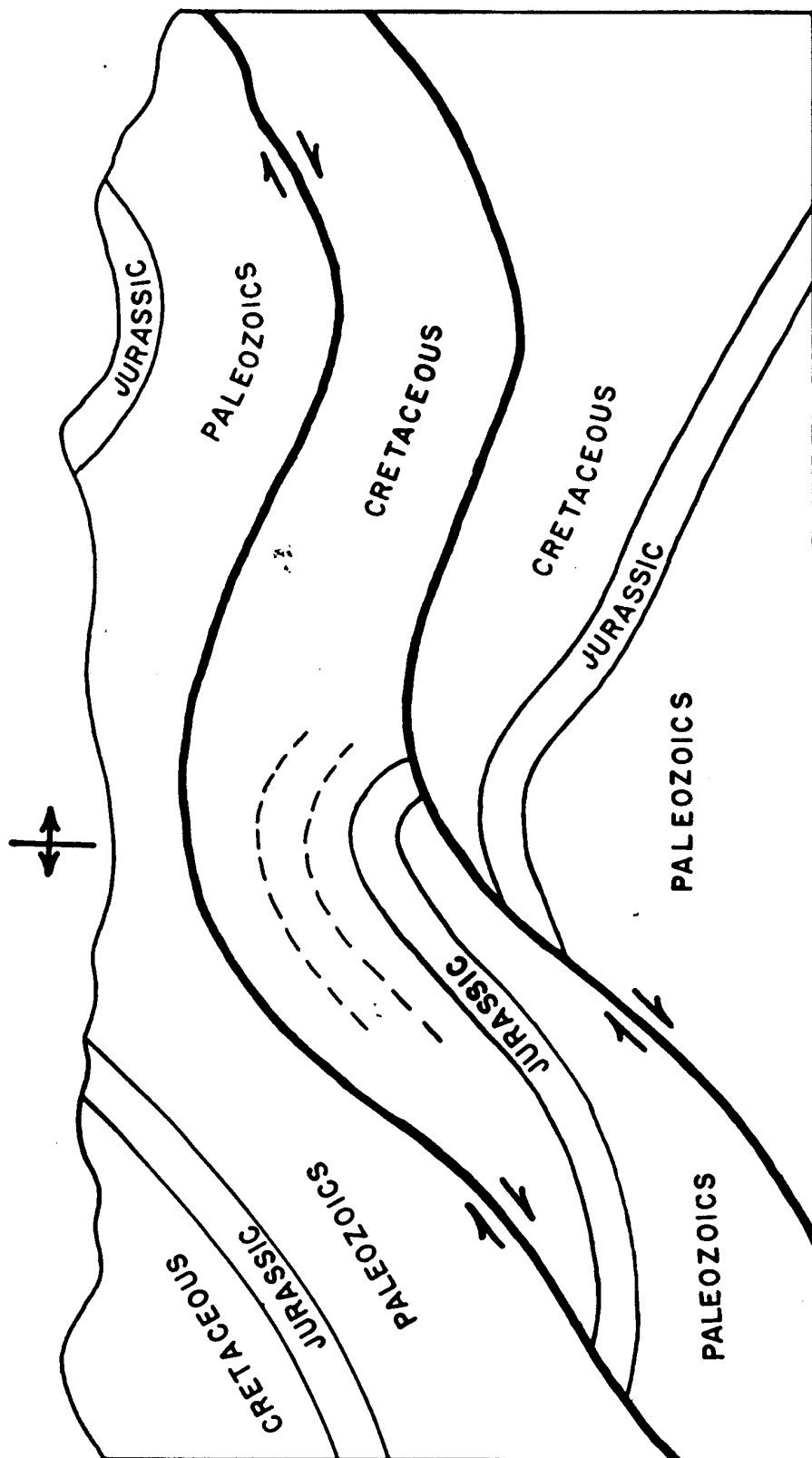


Figure 10. Diagrammatic Cross Section showing folded fault trap of Montana's Disturbed Belt. (HURLEY 1959)

The most recent drilling information from western Montana indicates a 38% success ratio in exploratory wells. Significant highlights are oil and gas production from the Cretaceous Greenhorn formation and the Mississippian Sun River Formation (TeSelle, Miller, Thames, Sonderby, Shepherd 1981). A new state depth record of 16,050 feet was set at Drummund in Granite County. The well was planned for 18,000 feet and consideration now is to take it to 20,000- 22,000 feet. After cutting several faults the well was working in Precambrian Belt metamorphosed rock (McCaslin 1981).

Figure 11 shows the lineation of the Overthrust fault and the numerous uplifts surrounding it. As was the case of the Moxa Arch near the Absaroka overthrust of Wyoming, these uplifts will act as structural controls for potential oil deposits beneath the overthrust.

Future exploration techniques will have to carefully consider the many varied aspects of the Montana Disturbed Belt. Consideration will have to be given to the possible inclined axial structures of many folds, therefore causing tilting of the axis at depth, to the structural control of the many basins and uplifts. In addition the many possible subsidiary faults which break the limbs of many anticlines, also causing offset axial surfaces will have to be considered (Woodward, Lee 1981).

All in all the prospect of discovering new hydrocarbon reservoirs in the Montana Disturbed Belt is an exciting challenge for the future.

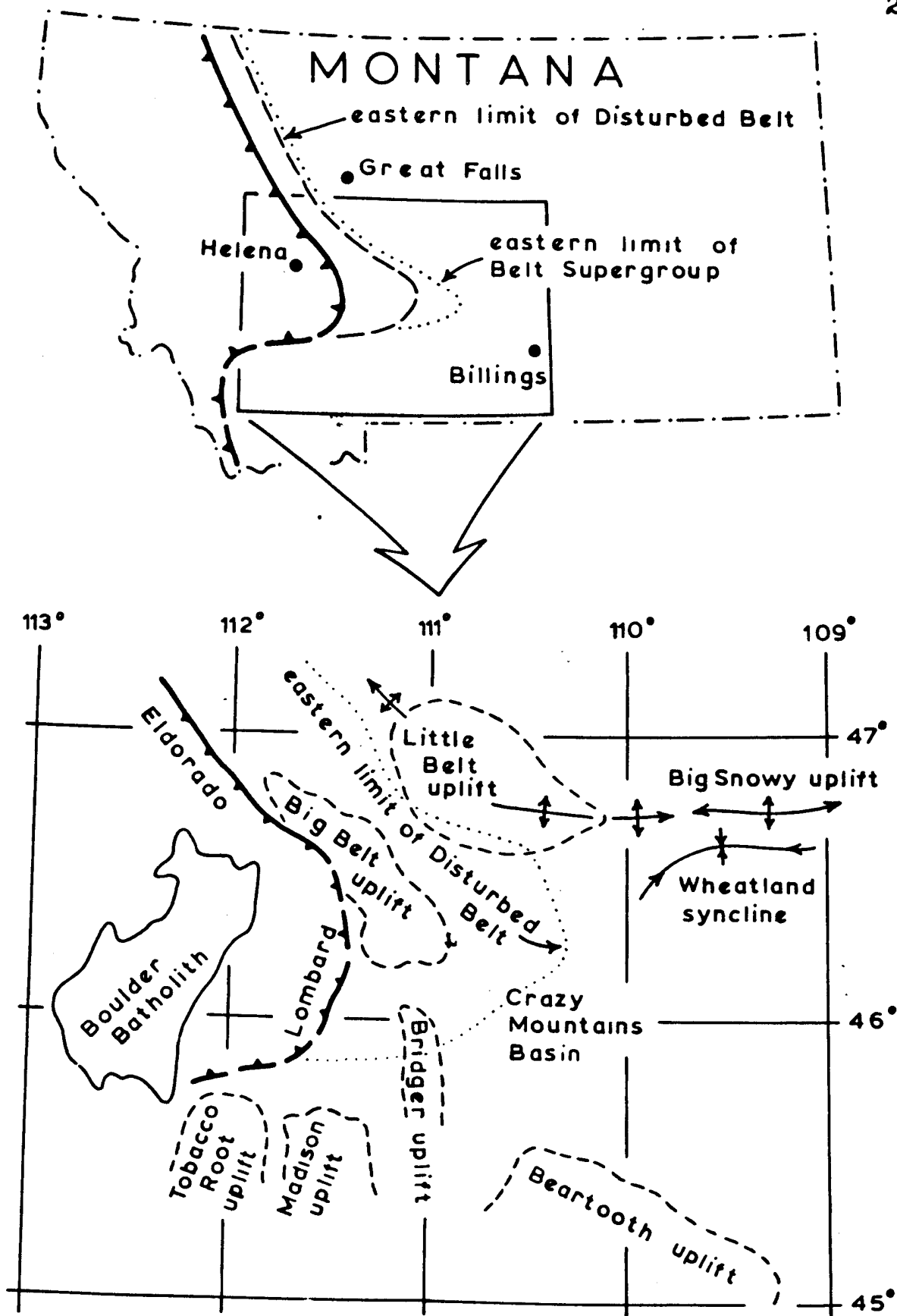


FIG. 11—index map showing major zone of overthrust faults, Disturbed Belt, and principal uplifts and basins of west-central Montana (modified from Harrison et al, 1974), (WOODWARD 1981).

Arizona

The potential for hydrocarbon accumulations along the overthrust of Arizona follows the same criteria for hydrocarbon accumulations anywhere in the country. Arizona though is probably the least explored state along the thrust belt. This is due to the great amount of pyroclastic material that covers the actual fault trace. Recent geologic and geophysical work in Arizona indicates the presence of deep troughs and large anticlines that are locally covered by multiple thrust plates (Hanson, Moulton, Owings 1980).

There are, in addition, good pre-thrust source rock in the Paleozoic, which include mudstones, dark gray cherty limestones, and highly organic Jurassic evaporites. Good reservoirs are possible in late Paleozoic marine sediments and in early Cretaceous reef structures and marine sediments (Smith 1981). There are marine sediments in the Sonora trough, just south of Arizona in Mexico, that are more than 45,000 feet thick. It is believed that these sediments range from Pennsylvanian to Cretaceous, and it is proposed that they can be projected north westward under the thrust plate in southwest Arizona (Hanson, Moulton, Owings 80).

Implacement of hydrocarbons and the development of trap structures was provided for during overthrusting and then later in basin-and-range block faulting. The conditions here are similar to the conditions found at the Pineview Field in Utah, a carbonate source rock, sand reservoir, and a salt seal (Smith 1981).

An additional factor in structural constraints found in Arizona, but not found elsewhere, is the effects of salt diapirism. Salt diapirism may

have caused additional fracturing in flanking reservoir rocks, increasing porosity and permeability. Exploration techniques used should include gravity surveys to locate salt, thus possibly increasing the chances for a petroleum discovery.

New Mexico

In the Overthrust belt of New Mexico, there exists a new set of problems. The thrust itself runs west north westerly through south western New Mexico and continues southerly into Mexico (Fig. 12). The major source and trap rocks that were present in the Idaho-Wyoming- Utah composite, are not present in south western New Mexico. There are no Triassic or Jurassic strata known in this area. There are, however, lower Cretaceous continental clastics and marine carbonate beds, which reach a thickness of approximately 15,000 feet. North of the thrust and fault zone these Cretaceous rocks become very thin or are absent (Woodward & Duchene 1981).

The primary reservoir rocks here are probably Paleozoic dolomites. The source rocks are Mesozoic mudstones and limestones. There have been shows of oil and gas in the Paleozoic rocks within the thrust belt. To date, though, no commercial accumulations of hydrocarbons have been discovered.

The northern liniation of the overthrust extends from the Peloncillo Mountains, on the New Mexico-Arizona border, to the Juarez Mountains in the east, at the New Mexico, Texas, Mexico border. The structure of the New Mexico thrust was formed during the Laramide orogeny of late Cretaceous to early Tertiary time. The New Mexico Overthrust is characterized by gently dipping thrust faults and tightly compressed overturned folds. Following the Laramide orogeny, there was widespread volcanism, that was followed by basin-and-range block faulting that produced the present topography. Because of block faulting the remnants of the overthrust are exposed only as patches within the block faulted ranges.

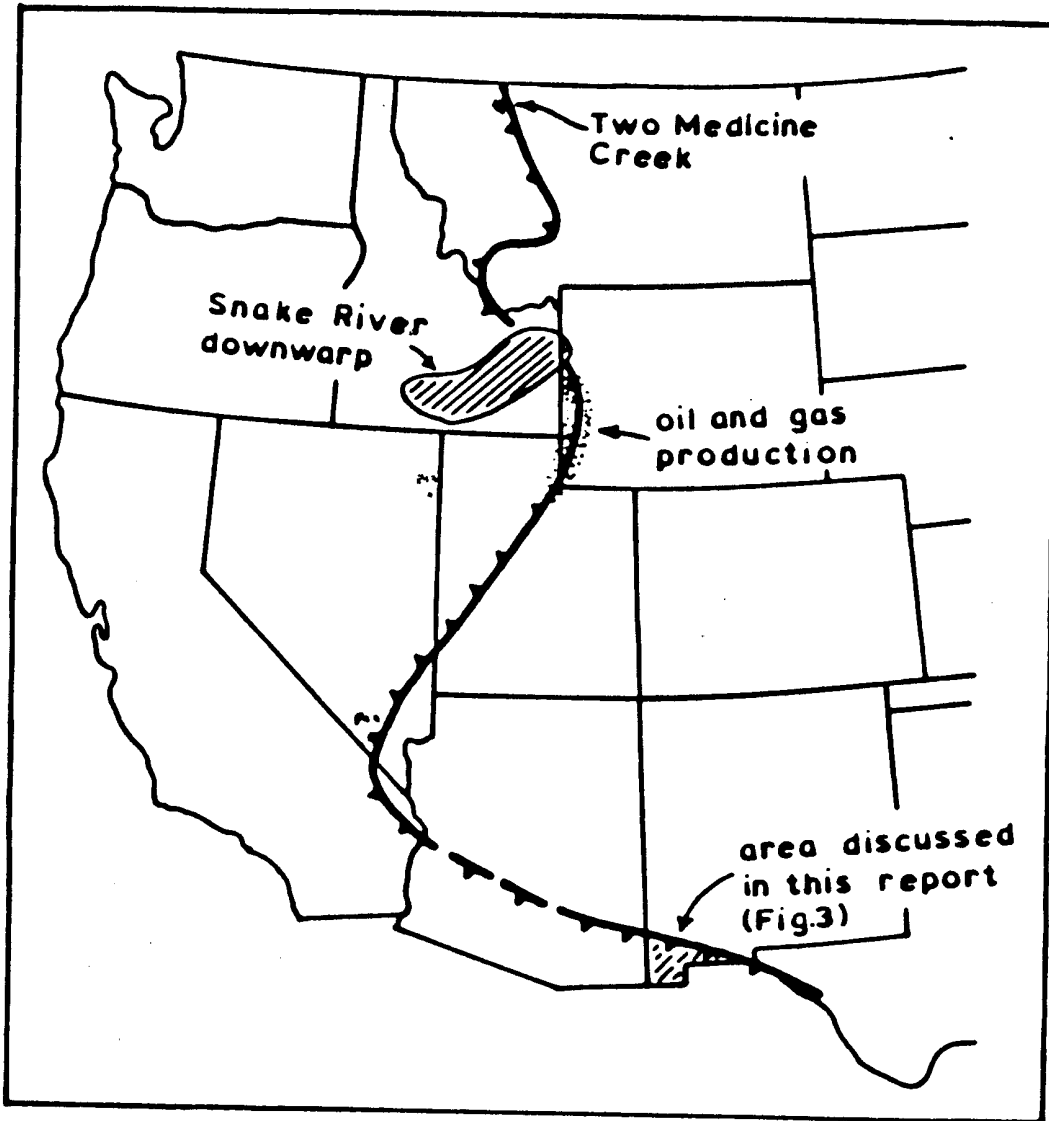


FIG. 12-Index map showing Overthrust belt, areas with commercial production of hydrocarbons, and area in southwestern New Mexico discussed in this paper.

(WOODWARD, DUCHENE 1981)

Many intermontane basins are also filled with Tertiary volcanic rocks and other clastic debris that cover the older structures of the fold and thrust belt (Woodward and Duchene 1981).

Although the Laramide orogeny produced many of the same structures in New Mexico that it did in other northern states aligned along the thrust belt, there are many new features that did not occur in the northern states, that add new structural controls in the exploration for oil and gas.

Major Tertiary volcanism and major deformation due to basin-and-range faulting, that occurred in south western New Mexico, did not occur in the northern sectors of the overthrust. The effects of the volcanism was to produce metamorphic halos around the intrusions. These halos may extend for a radius of up to one mile, and the heat from these igneous masses may have driven the petroleum from the sedimentary rocks over a much greater distance (Wengerd 1970). These intrusions probably are not a major cause, except as a local factor, in hydrocarbon destruction. They do however make up a large percentage of the surface outcrops. These severely limit the size and number of older surface structures which can be used to project the Laramide structures from one area to another (Woodward and Duchene 1981).

The hydrocarbon traps that formed from the thrusting and folding during the Laramide orogeny were born of compressive forces. Subsequently high angle basin-and-range faulting has been superimposed over these older structures. It is doubtful that older hydrocarbon trap fold structures survived, or were not at least partially destroyed by the tensional basin-and-range structures that are sharply oblique to the older structural trends (Woodward and Duchene 1981).

The ability for a trap to even contain hydrocarbons depends on whether there is a nearby source bed, and whether criteria needed for formation and expulsion of hydrocarbons has been met. The older the source bed the greater the chance that these criteria have been met. The closer the age of the potential hydrocarbon trap with that of the source rocks, the greater the chance that the trap will contain hydrocarbons. Conversely, the greater the age difference between the source rocks, and the potential trap, the less likely that oil and gas will have been trapped. This is one of the major problems in petroleum potential in south western New Mexico. The large time gap between structural reservoir rocks of late Cretaceous and early Tertiary and source rocks of Paleozoic age dim the potential for discovery of large scale petroleum accumulations.

Despite the limited area of the thrust belt in south western New Mexico and the large source to trap rock time gap, the possibilities are nevertheless good for commercial oil and gas production. This is indicated by the thick sections of Paleozoic and Cretaceous sedimentary rocks. Exploration of these locations will be severely hampered by the quantity of igneous intrusions and by the complicated subsurface geology (Wengerd 1970).

When exploring for hydrocarbon accumulations in the Overthrust belt of south western New Mexico there are a few basic steps to follow. First, avoid areas of large-scale igneous intrusions, or where broad basins are covered with pyroclastic and effusive rocks. These areas will generally be devoid of hydrocarbons unless the pyroclastics are from a

great distance, and not due to local intrusions. Secondly, explore areas where the strata exhibits relatively predictable lithofacies, as in the pre-Cretaceous. Of special importance are reef structures which trend southeast to northwest. These reef structures exhibit a higher porosity than surrounding strata and should be explored closely when the opportunity arises. They are, however, unpredictable structures, with lateral growth occurring through time. Thirdly, and most important, try to explore areas containing simple Laramide structural traps. These may be anticlines, with closure without low-angle thrust complications. Keep in mind that these low angle thrusts may be rejuvenated late Paleozoic folds. Finding Laramide anticlines is best accomplished by observing mountain exposures, and through aerial photography (Wengard 1970).

Summary

As has been seen, the overthrust model as a potential petroleum discovery, carries with it many complexing problems. To begin with, the mechanics of movement indicate that very specific conditions must be met to enable a thrust sheet to move without rupturing. Once an overthrust has been established, there is the difficulty of following the fault trace on the surface, as was noted in Arizona. The complexity of determining subsurface geology in a thrust zone, was seen in Figure 5. There are also controls placed on hydrocarbon distribution by basin-and-range block faulting. This faulting either causes pathways for accumulated hydrocarbons to escape or creates pathways to stratigraphically higher reservoirs and traps. If traps exist, what kind of traps are they and are they intact? The volcanism of New Mexico was cited for causing disruption of subsurface geology as well as hiding surface structures. There is the possibility that even if an overthrust exists, and can be traced, that criteria needed for hydrocarbon generation and expulsion have not been met. Certain criteria such as depth of source rock, age of source rock, degree of maturation, type of trap, and seal are all critical and must have been met.

John M. Parker (1979), a geologic consultant from Colorado, sums up the geologic uncertainties. "If sufficient population explosions of animals and plants occurred; if they matured into petroleum; if there is a reservoir rock which has sufficient thickness porosity and permeability to be economic; if there is a trap with sufficient capacity to be economic; if the trap seal does not leak; if the petroleum did migrate; if

subsequent geologic events did not destroy or remove the petroleum from the trap; if enough people obtain college degrees in geology; if they can find the trap; and if the find will yield hydrocarbons that can be sold for more than it costs to find and develop them; than a commercial field is present" (Parker 1979).

Conclusions

As a student of geology, I should be able to make a few tentative suggestions for future exploration. It is at this point, however, I should emphasize that this thesis merely scratches the surface of the overthrust model as a hydrocarbon potential. Due to the complexity and recentness of exploration in this area, I feel that there is cause for much new work to be done, and new information can be found in current editions of the American Association of Petroleum Geologists (AAPG) bulletins.

In an attempt to add credence to this paper, a few speculations for further exploration are given here. The overthrust region is characterized by a most complex geologic situation. Finding oil here, requires an understanding of the geologic history and lithology of the area before thrusting occurred. Structures present before the thrusting took place have been modified further by the era of thrust faulting. This episode not only canceled pre-thrusting structures, but it buried potential reservoirs to tremendous depths. Thus, exploratory drilling must penetrate thrust sheets thousands of feet thick, before reaching modern potential traps. Deep drilling is costly, and should such exploratory wells turn out to be dry holes, could discourage further wildcatting. The full potential of the overthrust belt will not be known until many more, expensive holes are drilled.

In closing it bears emphasizing that at today's high cost of exploration and production every effort should be made on the geologists

part to recommend drilling sites with the greatest probability of success. By paying close attention to regional structures as well as local, the discovery of new hydrocarbon accumulations can be greatly enhanced.

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